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Observations of Photospheric Magnetic Fields and Shear Flows in Flaring Active Regions

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Abstract

Horizontal flows in the photosphere and sub-surface convection zone move the footpoints of coronal magnetic field lines. Magnetic energy to power flares can be stored in the corona if the flows drive the fields far from the potential configuration. We show videodisk movies with 0.5 - 1 arcsecond resolution of the following simultaneous observations: green continuum, longitudinal magnetogram, Fe I 5576 Å line center (mid-photosphere), Hα wings ($\pm$ 600 mÅ), and Hα line center. The movies show a 90 $\times$ 90 arcsecond field-of-view of an active region at S29, W11 (15:05 - 16:25 UT, 8/6/87). When viewed at speeds of a few thousand times real-time, the photospheric movies clearly show the active region fields being distorted by a remarkable combination of systematic flows and small eruptions of new flux. Magnetic bipoles are emerging over a large area, and the polarities are systematically flowing apart. We have mapped the horizontal flows in detail from the continuum movies, and these may be used to predict the future evolution of the region. The horizontal flows are not discernable in Hα. The Hα movies strongly suggest reconnection processes in the fibrils joining opposite polarities. When viewed in combination with the magnetic movies, the cause for this evolution is apparent: opposite polarity fields collide and partially cancel, and the fibrils reconnect above the surface. This type of reconnection, driven by sub-photospheric flows, complicates the chromospheric and coronal fields, causing visible braiding and twisting of the fibrils. Some of the transient emission events in the fibrils and adjacent plage may also be related. The flows in this region probably also cause some reconnections beneath the surface, leading to U-shaped magnetic loops as well as Ω-loops.

Longer sequences with more uniform seeing, as would be obtained from balloon or space flight, are sorely needed. These observations were obtained at the Vacuum Tower Telescope (NSO/Sunspot) using the SOUP tunable filter and the HRSO CCD camera. This work was supported by Lockheed Independent Research Funds and NASA contracts NAS8-32805 (SOUP) and NAS5-26813 (HRSO).

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Evolution of the Active Region

Once the fields have emerged, AR's continue to grow and deform, often increasing in magnetic complexity and in stored magnetic energy. Large scale flows have traditionally been observed using pores and sunspots as tracers. Using SOUP data, we discovered that granulation can be used to measure accurate horizontal flow velocities anywhere on the sun. More recent work at Lockheed and NSO (by November and Simon) has shown that this can also be done with ground-based data if long enough time series of approximately uniform quality are available. We have now used the same techniques on magnetograms, to separate the systematic motion of magnetic features on the sun from the random jiggling due to seeing.

The August 6 magnetic movie, after removal of the seeing jitter, shows that the polarities in the region are separating systematically over a large area. This is shown very dramatically on the video movies: white polarity features move down and to the left, and black polarities move up and to the right. This rule characterizes the proper motions throughout the region between the spots. Presumably, the magnetic features of each polarity represent the frayed ends of a large flux rope in the convection zone. As the ropes separate down below, the ends are dragged apart at the surface. With better observations, it will be interesting to see when magnetic features move "against the current" of the meso- and supergranular flows (measured from proper motion of non-magnetic granulation). This would indicate very strong buoyancy and tension forces at work to overcome the drag force of the surroundings.

We have mapped the photospheric flow of the granulation and pores by correlation tracking on the continuum movie. Some of the flow features of the magnetic movie are seen, but the flows do not agree everywhere. Future evolution of the region is simulated using the measured flows; again, the agreement is mixed. The correlation tracking technique breaks down if, for example, a pore is moving against a steady flow of granulation, and both are included in the tracking field-of-view. With better resolution and less seeing jitter, it may be possible to separate the magnetic and non-magnetic flows.

Another discovery from the August 6 magnetic movie is that flux emergence in this region does not take place at a neutral line separating separating polarities. Instead, it is occuring in small bipolar events spread over a large area between the leading and following spots. Even a snapshot shows that the polarity mixing makes it impossible to draw a neutral line. The movie shows that the opposite poles of an emerging bipole separate and then move rapidly across the "neutral zone" to flux concentrations on either side. The motions are not always at uniform speed–sudden spurts are often seen.

A very important consequence of this geometry is that many flux cancellation and recon-

nection events are forced to occur among the newly emerged magnetic elements. With opposite polarities moving in opposite directions through the same area, collisions are frequently observed. Cancellation of flux occurs, sometimes forming a temporary lane of one polarity. In some cases, dramatic reconnections of the H-α fibrils are seen when the magnetic footpoints of a set of fibrils are cancelled by intrusion of opposite polarities. This is very graphic evidence for magnetic reconnection taking place above the surface, presumably in the low chromosphere. These reconnections are driven by sub-surface flows, not by global properties of the chromospheric or coronal fields. Therefore, they have no tendency to simplify the topology of the magnetic field, and considerable twisting and braiding of the H-α fibrils is observed in our movies after a reconnection. This process can store energy in the field for coronal heating or flaring, as discussed in detail by Parker, van Ballegooijen, and others.

It is likely that some collisions between opposite polarity flux tubes occur beneath the surface. Before emerging through the surface, the field lines are nearly horizontal, and this must persist for some time afterwards as well. The inclined field lines of different flux tubes can therefore meet and reconnect below the surface, forming shallow, U-shaped tubes. These are weighted down by the gas frozen into the magnetic tube and cannot float up through the photosphere and out into the corona. U-loops have been suggested by Spruit et al. to play a role in the destruction of active region flux.

FIGURE CAPTIONS

Fig. 1. Snapshots of the active region in (a) continuum near 5576; (b) Fe I 5576, 30 mÅ blue; (c) H-α line center; (d) H-α wing, 600 mÅ red. All images in Figs. 1 and 2 were taken within 80 seconds of each other, in one cycle of the observing sequence. Field-of-view is 90 $\times$ 80 arcseconds, and ticks are at 2 arcsecond intervals.

Fig. 2. Same as Fig. 1, showing (a) Fe I 5576 line center, compensated for the local Doppler shift; (b) Doppler velocity measured from 4 images evenly spaced through 5576 (g=0 line); (c) H-α wing, 600 mÅ blue; (d) magnetogram made in blue wing of Fe I 6302 (g=2.5).

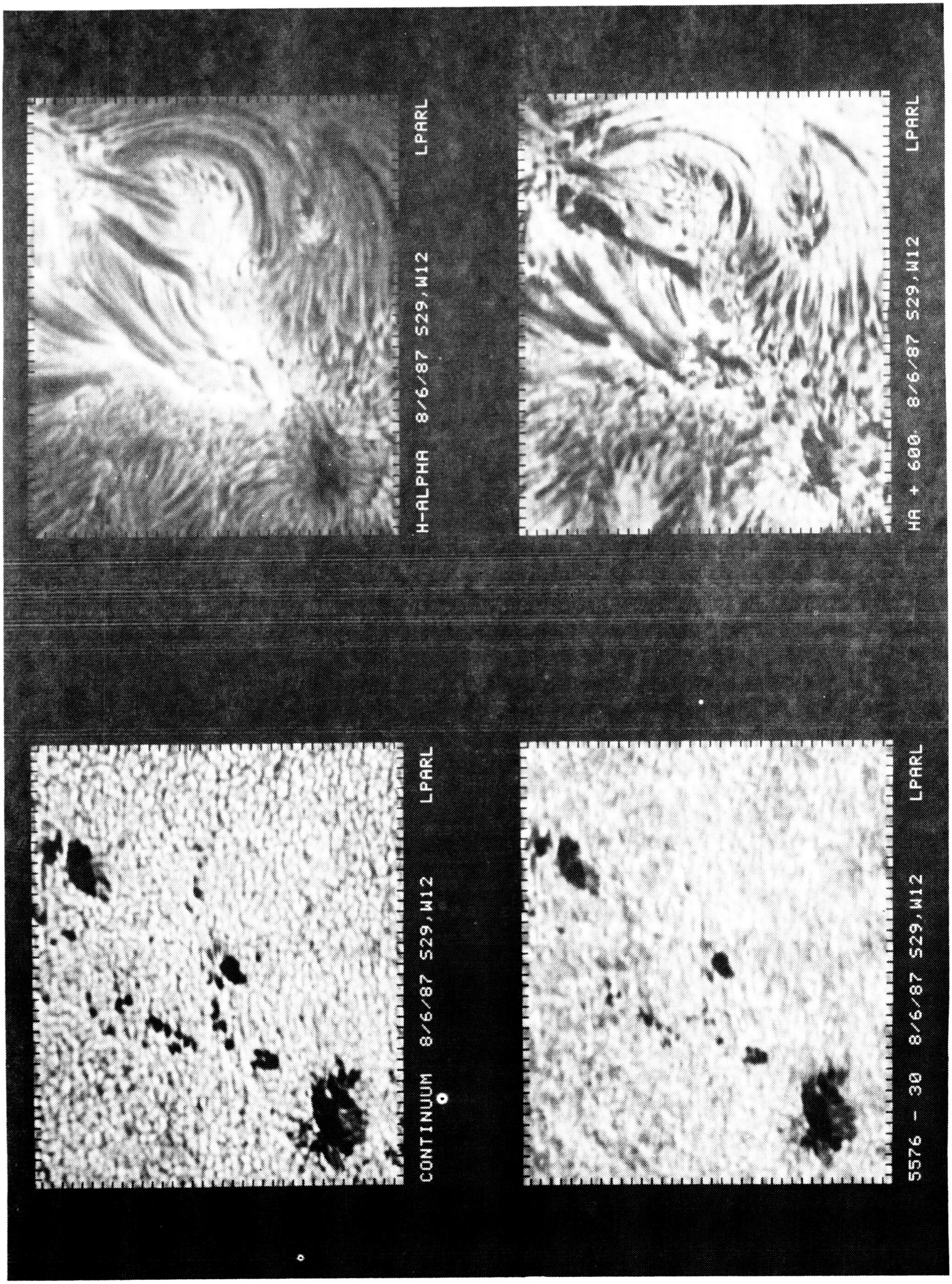
Fig. 3. Horizontal flow vectors (measured by correlation tracking on the continuum movie) overlain on a magnetogram. Many meso- and supergranules (diverging flows) can be seen as well as magnetic concentrations in converging flows.

Fig. 4. Two frames from a "cork movie" simulation of future evolution of the region based on the measured flows of Fig. 3. The clocks show the elapsed time from the initial condition of a uniform array of markers ("corks").

Fig. 5. Collage of frames from the H-α line center movie, showing the major reconnection event, and one magnetogram. Each frame is labelled with the time. Field-of-view is 45 $\times$ 45 arcseconds, and ticks are at 1 arcsecond intervals.

Fig. 6. Collages of frames from the H-α line center and red wing movies, showing the major reconnection event. Field-of-view is 25 $\times$ 25 arcseconds, and ticks are at 1 arcsecond intervals.

Fig. 7. Same as Fig. 6 for H-α blue wing and magnetogram movies. Initially the fibrils connect a small white polarity feature just to the right of center to the large black-polarity sunspot above this field-of-view. The growth and encroachment of the adjacent black polarity causes the reconnection. Afterwards, the fibrils connect the black sunspot to the strong white polarity just above the time label.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HA + 600 8/6/87 S29,W12 LPARL
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FIG. 1

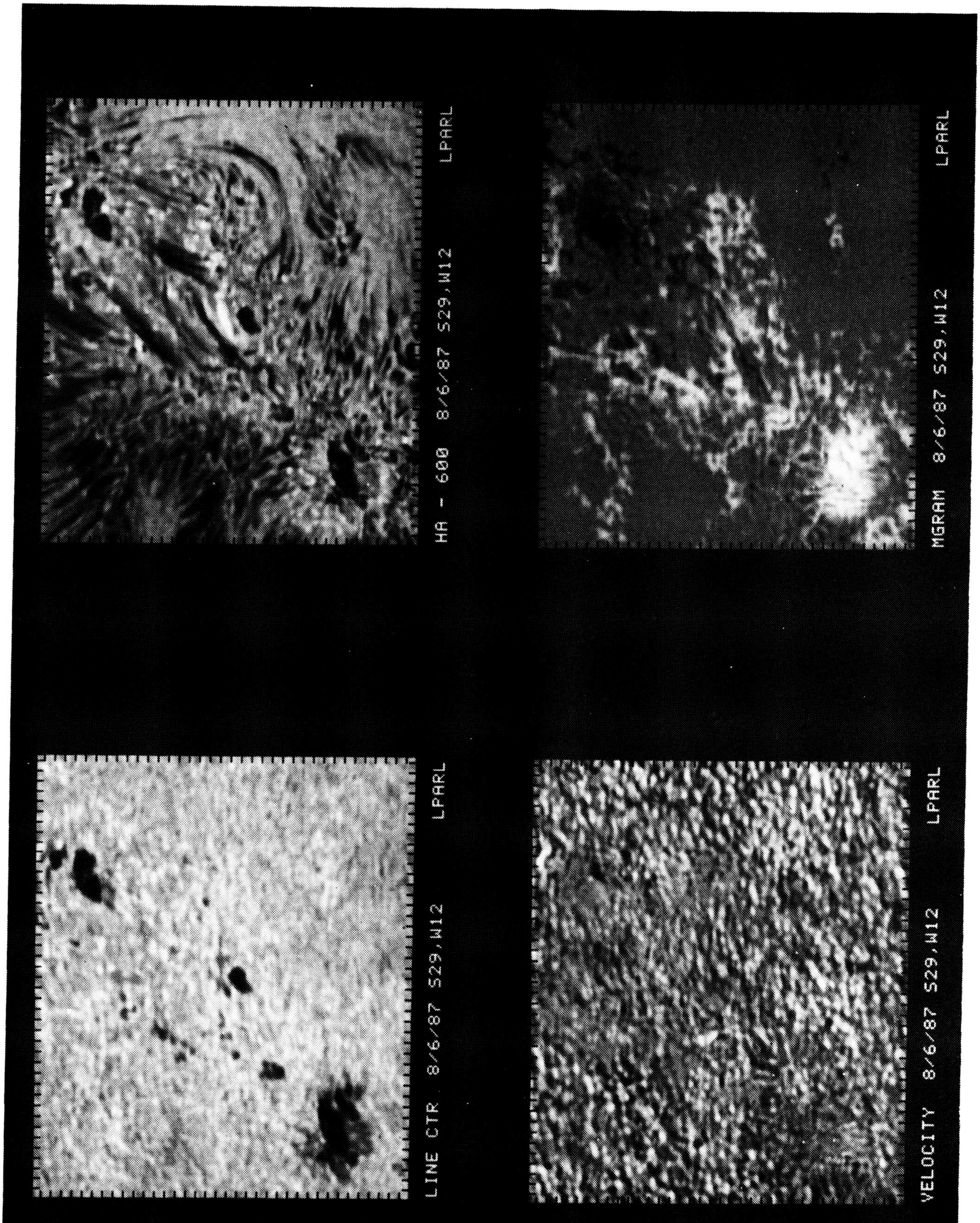
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FIG. 2

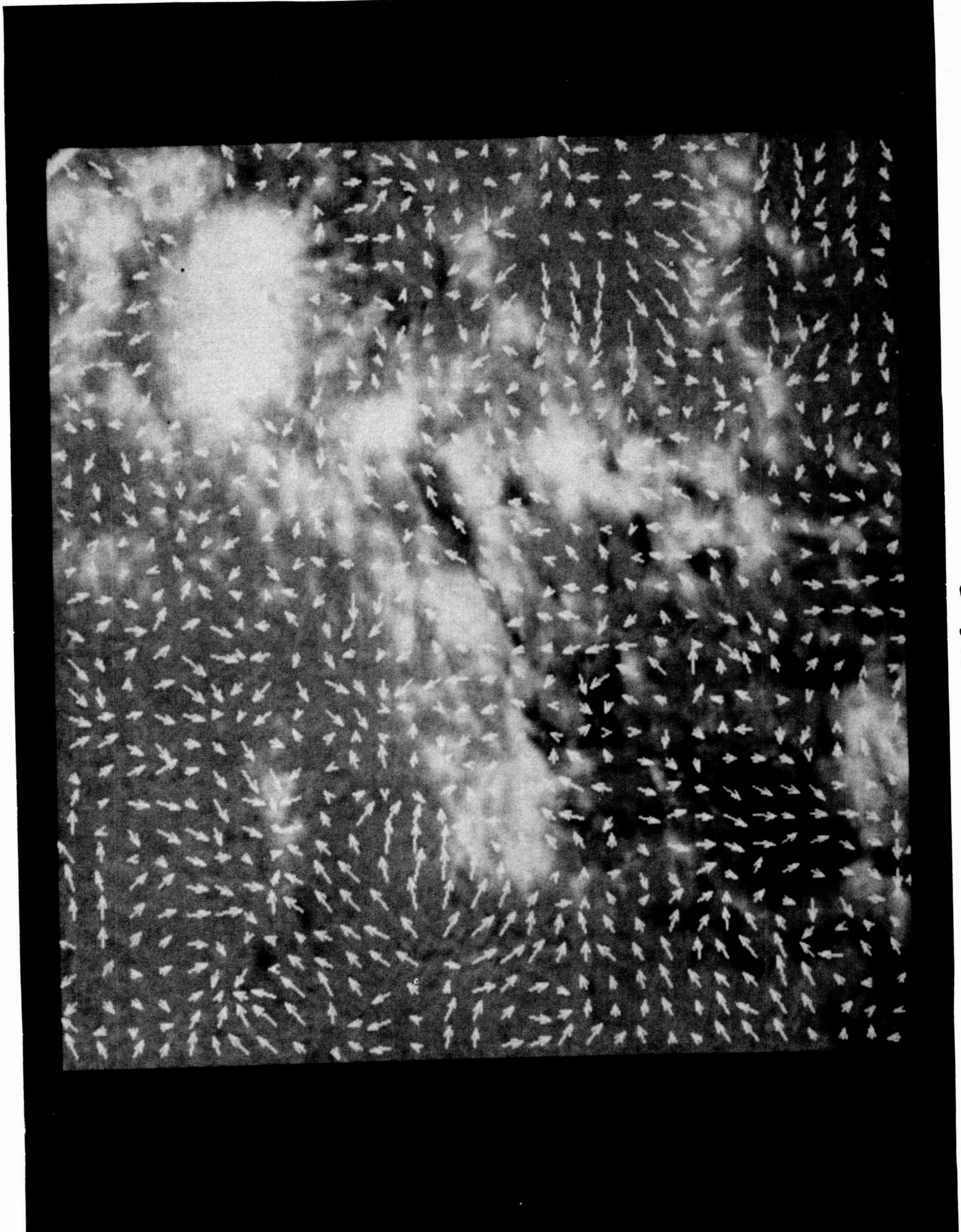

FIG. 3

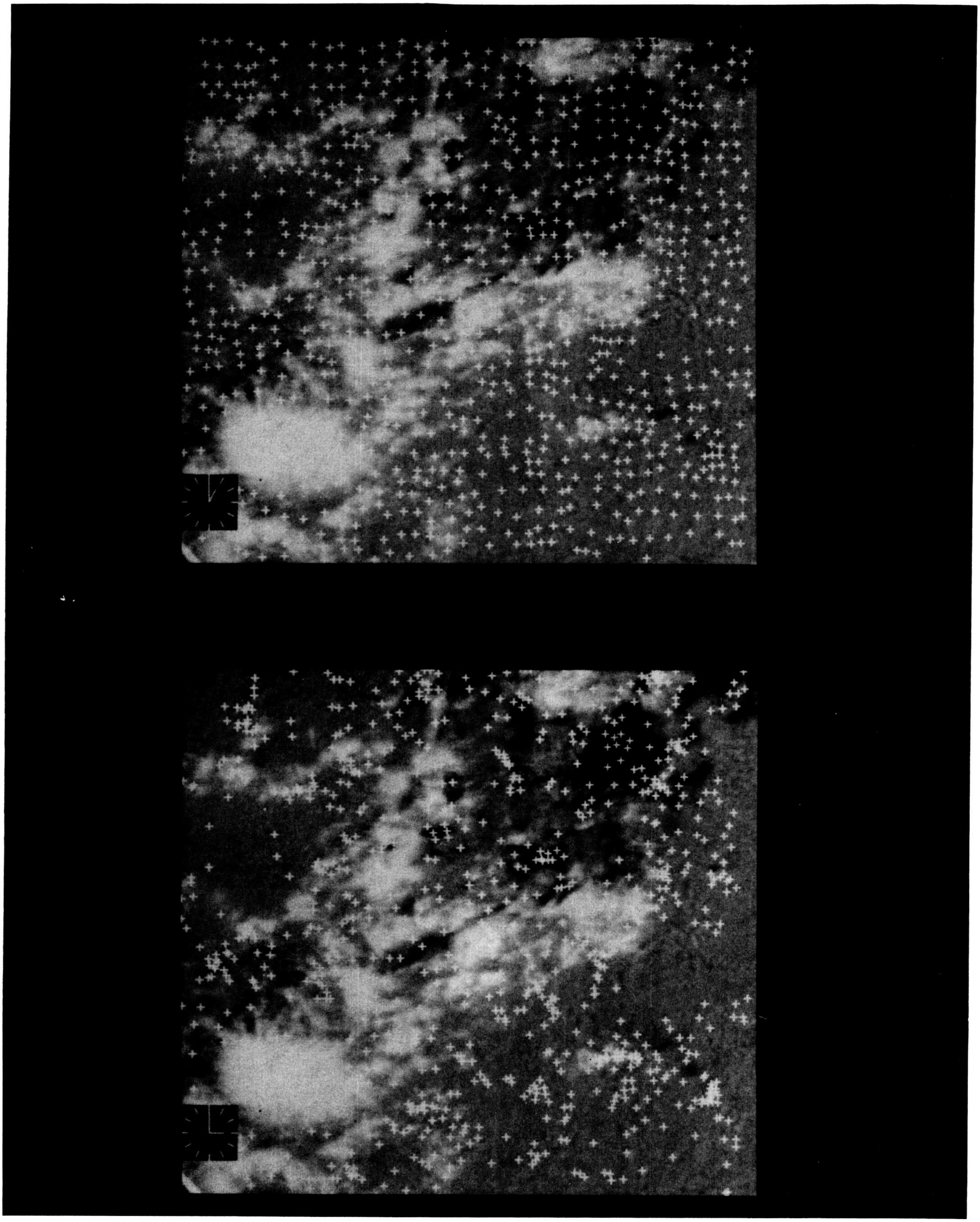

FIG. 4

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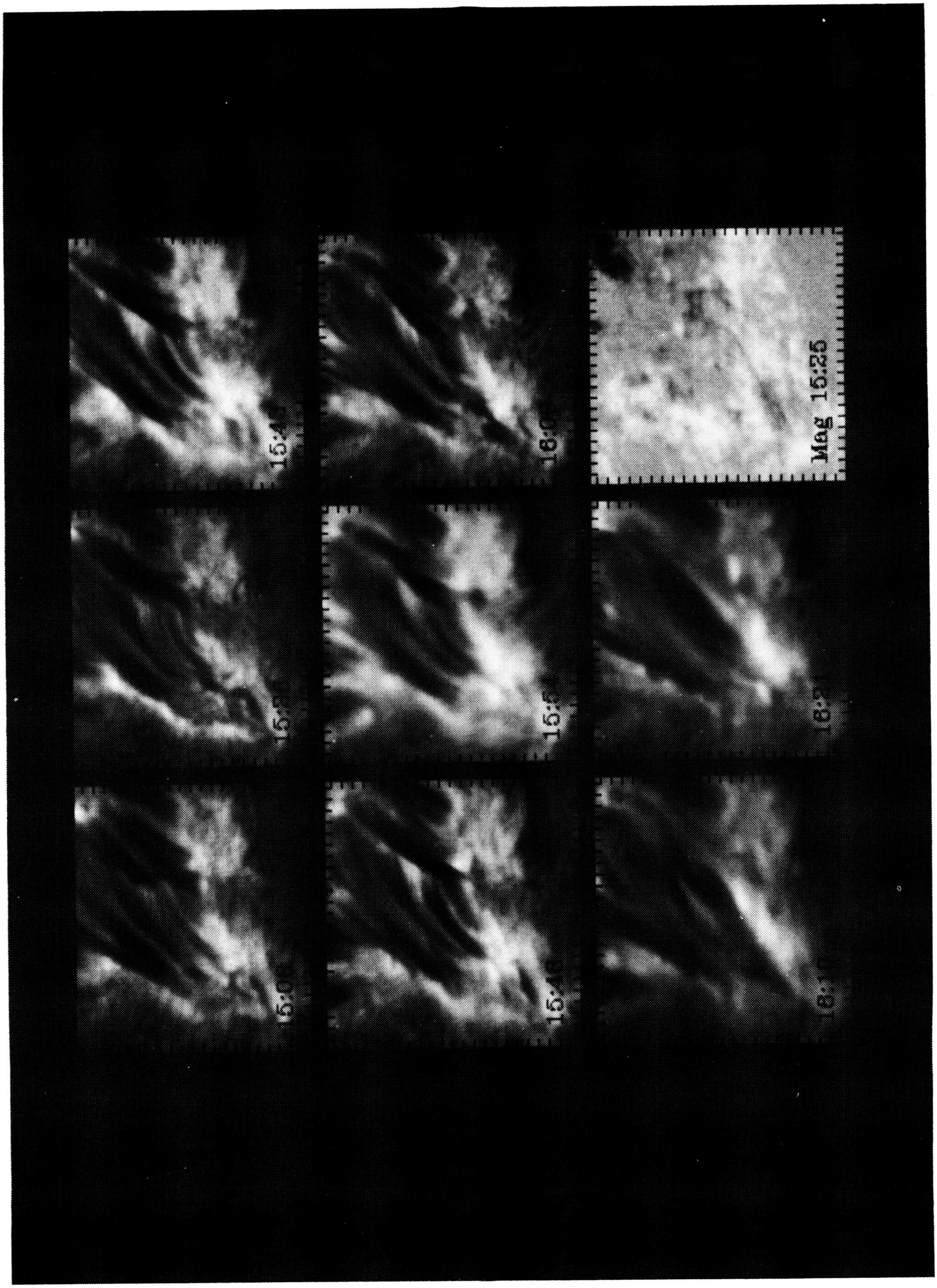
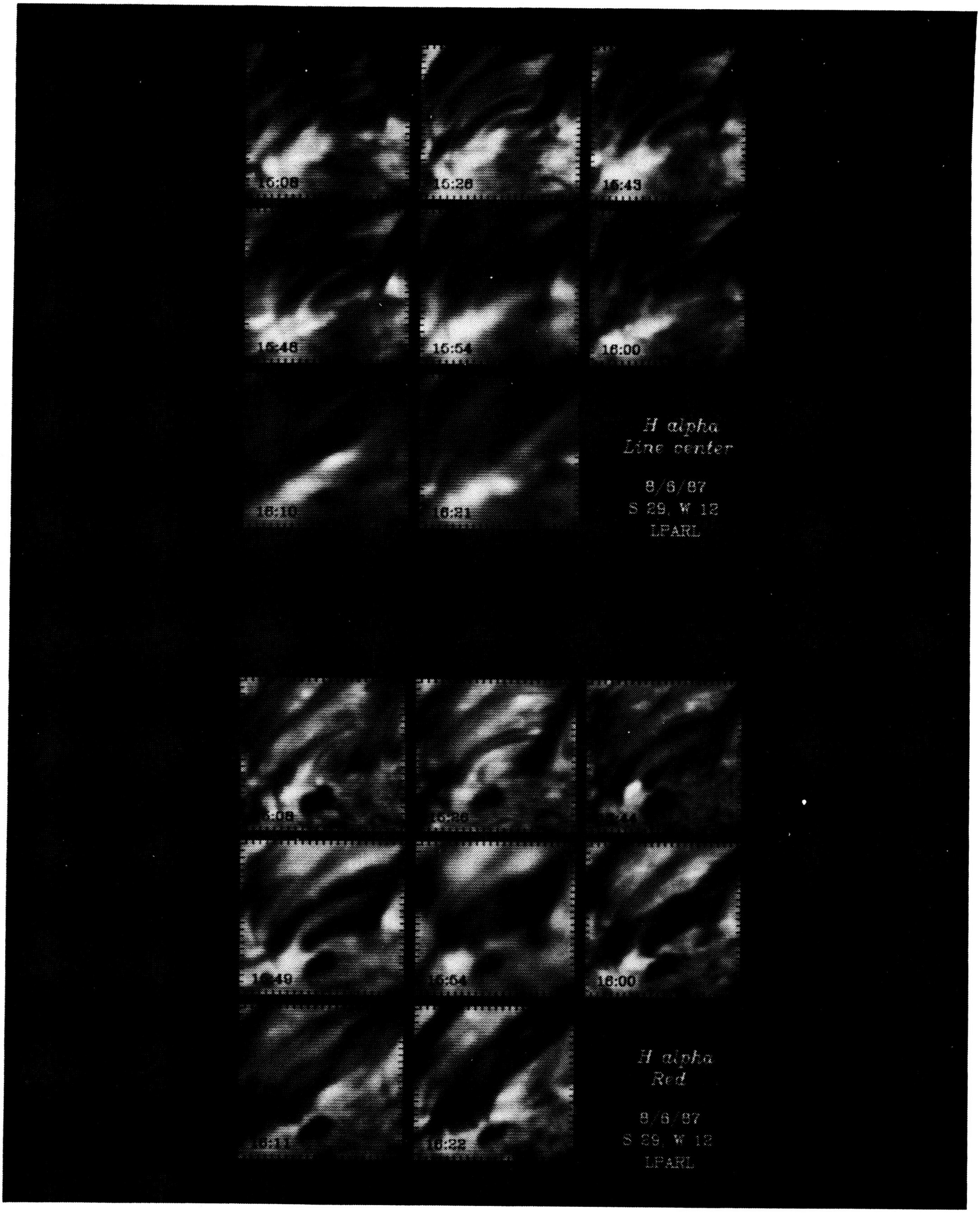


FIG. 5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8/6/87
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LPARL
15:26
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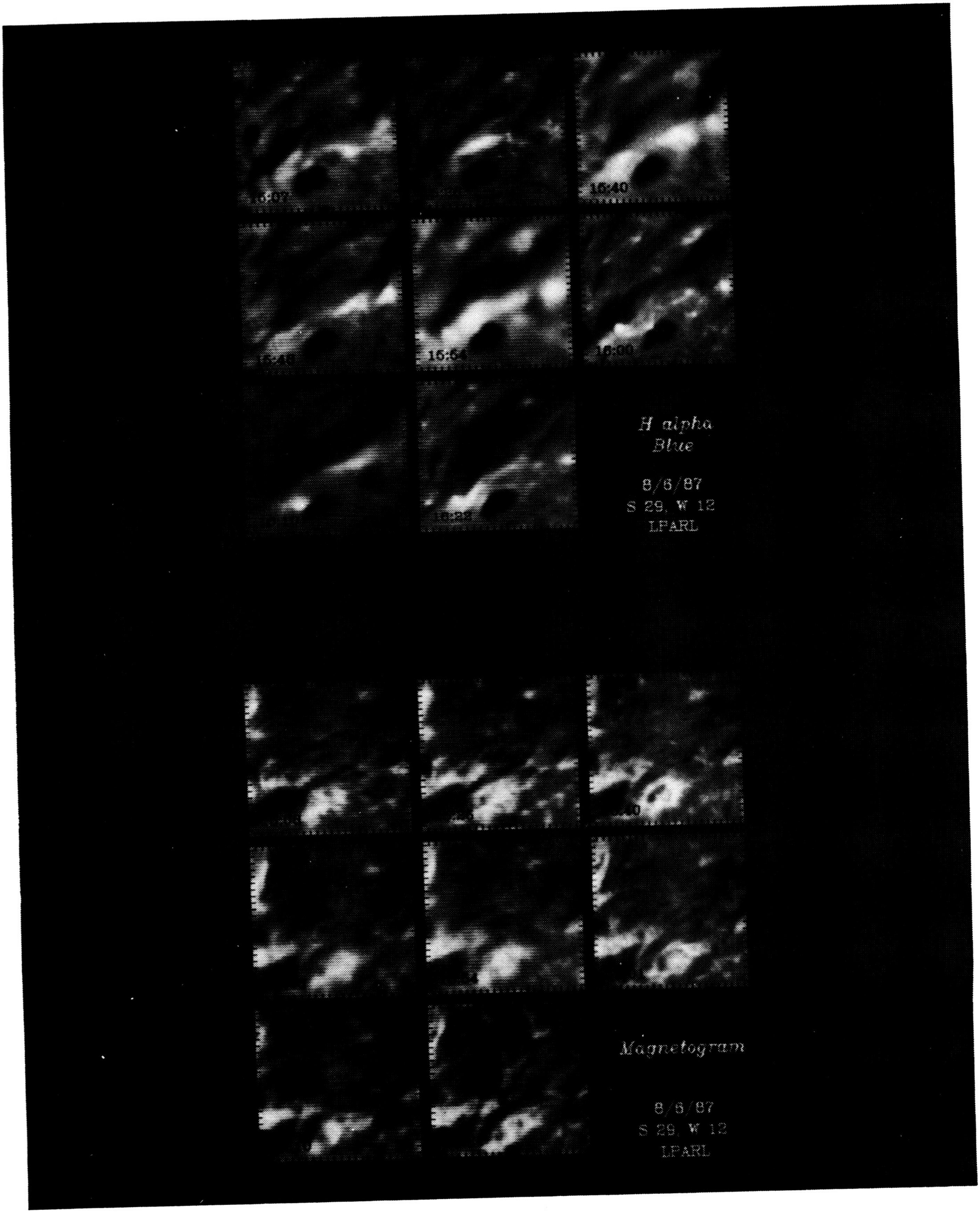
Red
8/6/87
S 29, W 12
LPARL

FIG. 6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Magnetogram
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LPARL

FIG. 7